EFFECTS OF CALCIUM FERTILIZATION AND ACID MIST ON CALCIUM CONCENTRATION AND COLD TOLERANCE OF RED SPRUCE NEEDLES

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Several studies have shown that exposure to acid mist impairs cold tolerance of red spruce foliage, predisposing it to winter injury, which appears to be a major factor in the decline of montane populations of the species. Other studies have shown increases in calcium (Ca) concentration in canopy throughfall in montane spruce-fir forests, and decreases in foliar Ca concentration associated with exposure to acid mist. Studies of other plant species suggest that Ca may play a role in the development of cold tolerance or in stress response to cold. These considerations have led to the specific hypothesis that the reduction in cold tolerance associated with exposure to acid mist is caused by reduction in foliar Ca. To test this hypothesis, we applied Ca fertilizer to trees in a 33 year old red spruce provenance plantation in Colebrook, NH, and used branch chambers to expose individual branches to mist of known composition.

Ca fertilizer was applied during the 1992 and 1993 growing seasons. It was applied on the ground in a 1 m diameter circle around the base of designated trees, during bud break, in two stages, two weeks apart: $CaCO_3$ at a rate of 200 kg ha^{-1} Ca, and Ca Cl_2 at a rate of 800 kg ha^{-1} Ca. To test the simple effect of fertilization, we determined Ca concentration ($\mu g\ g^{-1}$) and cold tolerance of foliage collected in December 1992, after the first round of fertilization. Fertilization significantly increased Ca concentration of current year foliage from a mean of 902 to 1277 μg g-1 in the unfertilized and fertilized groups, respectively (n = 12 trees in each group). There were no differences in cold tolerance attributable to fertilization (Table 1).

Table 1. Statistical analysis of cold tolerance data. Probabilities from analyses of variance of critical temperature (1992) or Tm (1993-94). Separate analyses were conducted for each date. Values significant at $p < 0.05$ are given in boldface. * 8 degrees of freedom for February 1994; 2 trees were omitted due to severe injury.

Source	df	Dec 92	df	Oct 93	Dec 93	Feb 94
Fertilization	1	0.1082	1	0.931	0.136	0.278
Tree[Fert]	22	0.0002	10*	0.291	**0.003**	**0.007**
Mist			2	0.549	0.073	**0.032**
No chamber vs. chamber			1	0.302	0.318	0.825
pH 3.2 vs. pH 5.6			1	0.744	**0.038**	**0.010**
Mist * Calcium			2	0.491	0.553	0.204

The design of the final stage of the experiment was a split-plot, with trees as whole plots, fertilization as whole plot effect, and mist treatment as a subplot effect. During the 1993 growing season, branch chambers were used to expose two branches on each of 12 trees, 6 fertilized and 6 unfertilized, to either pH 3.2 or pH 5.6 mist. The following autumn and winter, we determined Ca concentration and cold tolerance of foliage from treated and untreated (no chamber) branches from each tree in October, December, and February.

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There were no significant effects of any treatment, including fertilization, on Ca concentration. Mean Ca concentration of the unfertilized group increased after the second round of fertilization (Figure 1). Trees in the plantation were closely spaced, and roots of unfertilized trees may have extended into and absorbed Ca in fertilized areas. While branches misted at pH 5.6 on fertilized trees had substantially more calcium than any other group, this difference was not significant at $\alpha = 0.05$ in either the planned analysis of variance or *a posteriori* multiple comparison procedures.

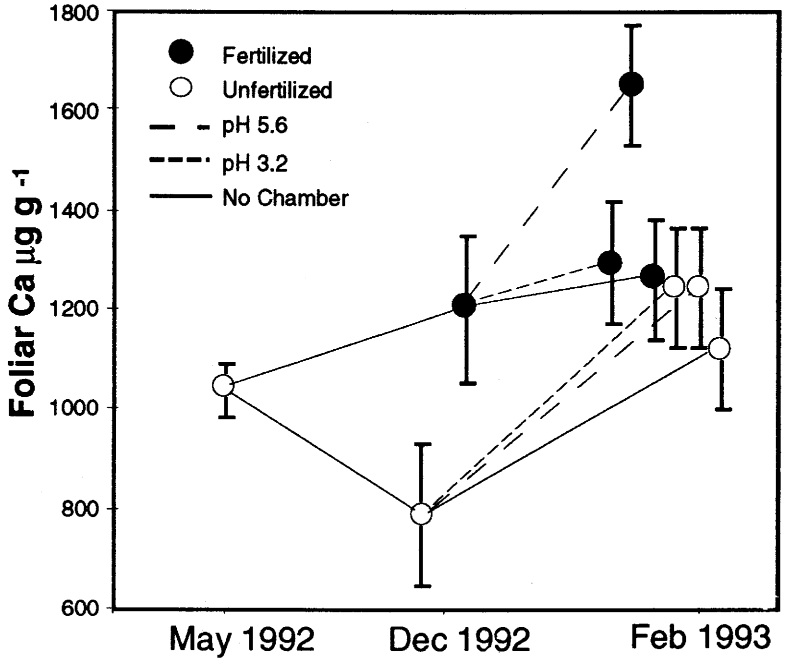

Figure 1. Changes in foliar Ca concentration over the course of the experiment. The May 1992 point is the mean ± standard error of three branches in each of 54 trees. For the later dates error bars are standard error estimates from analysis of variance. The December 1992 points each represent 12 trees, and the December 1993 points represent 6 treated branches.

We found no significant difference in cold tolerance due to any treatment for foliage collected in October, and no significant difference attributable to Ca fertilization or its interaction with mist treatment on any date (Table 1). In the winter, branches exposed to pH 3.2 mist were significantly less cold tolerant than those exposed to pH 5.6 mist, with a mean difference of 4.4 °C in December and 5.2 °C in February (Figure 2). Simple correlation between Ca content and cold tolerance was weak ($r^2 = 0.22$) but significant ($p < 0.01$, $n = 36$), with no strong influence of either mist or fertilization on the relationship.

The clear effect of acid mist on cold tolerance lends strong support to the conclusions of earlier studies that exposure to acid mist can significantly impair cold tolerance. Our results do not support the hypothesis that this effect is mediated by foliar leaching of Ca. The lack of strong effects of mist on Ca concentration and of fertilization on cold tolerance, and the weak and inconsistent correlation between Ca concentration and cold tolerance all argue that the two responses are not directly related. However, results are uncertain because of the poor separation of Ca concentration in fertilized and unfertilized groups in the second year of the study.

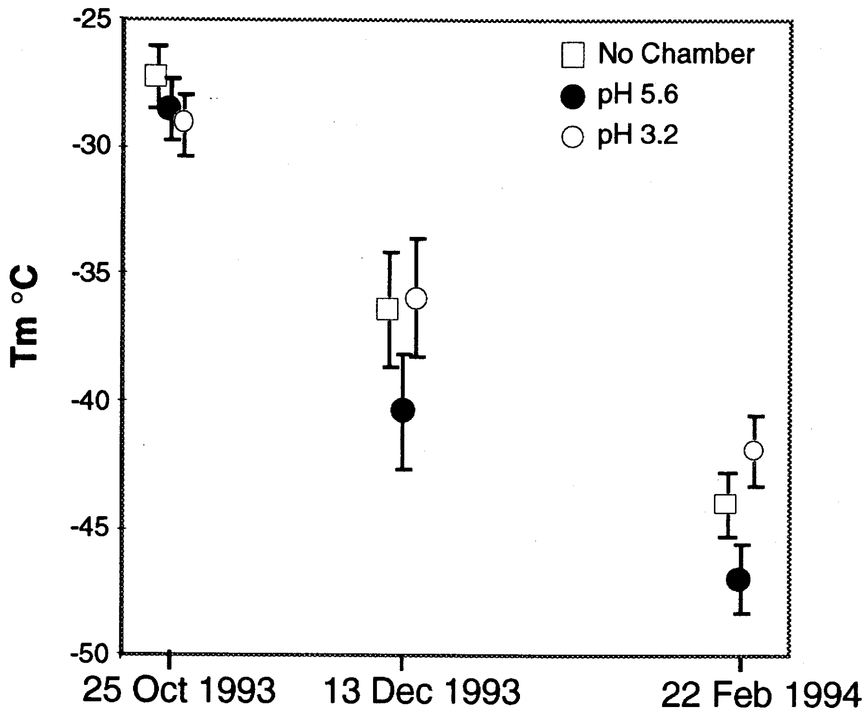

Figure 2. Mean Tm (an estimate of cold tolerance) by mist treatment on three dates. Error bars are standard error estimates from analyses of variance for each date.